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Knowledge Transfer Partnership. Adding value to UK grown timber in construction

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ABSTRACT

The Knowledge Transfer Partnership (KTP) is a programme that encourages collaborations between business and academia in order to increase competitiveness and innovation in industry. The main benefits of KTPs are to provide industries with increasing profitability as a result of the quality improvement by production method optimisation and new product development that can create access to new markets. This project is held between Clifford Jones Timber Ltd and the BioComposites Centre of Bangor University in order to add value to, so far undervalued UK grown softwood timber. In the UK's building materials market, sawn timber is the third most imported material (National Statistics 2017). Sitka spruce, Scots pine and Larch are the most common timber resources in UK, with Spruce accounting for 62% of the overall resources (Forestry Commission 2011). Softwood grown in the UK is fast grown, which can cause major defects such as bowing and warping when dried to 12% MC or lower (Crawford et al. 2015). Several studies suggest a solution to drying UK grown timber to 12%, is to introduce medium-high heat and steam during the drying process. The high temperature and steam enables the relaxation of lignin and aids in restraining the massive twists, which are observed with conventional drying methods (Riepen et al. 2004, Cooper and Cornwell 2005). Cross laminated timber (CLT), which is not yet produced in the UK, seems a suitable alternative product that can utilise timber not currently considered for structural purposes. Crawford et al. (2013) had proved that it is possible to produce CLT made of Sitka Spruce with very promising results. This projects aims to the development of a CLT product made by UK grown timber and transfer the academic knowledge to the industry through the process.

INTRODUCTION

Knowledge Transfer Partnerships (KTP) is a UK funded programme that helps businesses to grow through innovative solutions. KTP scheme was established at 2005 as a replacement of the former similar scheme Teaching Company Scheme (TCS), which had been formed in 1975. Since then the idea of the knowledge transfer has delivered increasing profitability for industries as a result of the quality and operational improvement, increasing sales and openings to new markets by the development of innovative products. The aim of the KTP scheme is to translate the academic knowledge to direct commercial improvement of business. The KTP is consisted by three partners, a business, an academic institution with an associate who acts as the project manager. The associate is employed by the academic institution and works for the company whilst being supported both the academic institute and the company. The role of the associate is to introduce new skills and knowledge to the industry that can be translated to increase profitability by innovation.

This particular KTP project partners are the Clifford Jones Timber Ltd (CJT) and the BioComposites Centre (BC) of Bangor University and the aim is to add value to UK grown softwood timber by introducing them into the building market as a construction material. UK grown softwoods are mainly used for fuel in the form of pellets or briquettes and in wood panel and paper production as they are considered unsuitable for construction timber. The reason for this is that UK grown softwoods are very fast grown, and the very wide growth rings. This can cause major defects such as bowing and warping when dried to 12% MC or lower which is the requirement for construction timber (Crawford et al. 2015). Defecting material is rejected from timber graded timber and cannot be used in construction. Therefore, to reduce the quantity of rejected material, UK sawmills produce UK grown sawn timber dried to a minimum MC of 20%. However, these timbers are only suitable for outdoor products such as fencing poles.

CJT currently produces fence poles and laminated beams for outdoor constructions such as in playgrounds. The timber used for the laminate products, is imported pine, which, if it can be replaced by a local grown softwoods, can significantly increase the profitability of the company. This will also open up a completely new market for the undervalued UK timber.

A method to dry UK grown spruce down to 12% is the use of medium-high heat and steam drying process which has been evaluated by several studies. The hypothesis behind this method is that the high temperature and steam will lead to the relaxation of lignin and will aid in restraining the massive twists which are observed with conventional drying methods (Riepen et al. 2004, Cooper and Cornwell 2005). However the large scale optimisation of this process still needs to be investigated and improved. During the drying process there are three major complex interactive mechanisms that must be considered; the heat and moisture transfer, the phase change of the free and combined water and the glass transition temperature of lignin. The interaction of these complex mechanisms will ultimately affect the final timber product. However, if these mechanisms can be simulated as a multiphysic equation through finite element analysis it is possible to predict the drying outcome and aid in optimisation of the drying schedule for the best possible product.

During this KTP project heat and moisture transfer within the wood during the drying process are monitored in order to predict the behaviour of UK grown timber, dried to a moisture content below 20%. The collected data will be used to create a simulation that can be used to model and optimise the drying procedure for achieving an economically viable method of drying local grown timber for the production of construction timber. As UK softwoods are fast grown species, the best end product candidate seems to be the cross laminated timber (CLT) as it is not yet being produced in the UK. The most common softwood forest resources in UK are Sitka spruce, Scots pine and Larch, with Spruce accounting for 62% of the overall resources (Forestry Commission 2011). Crawford et al. (2013) had proved that it is possible to produce CLT made of Sitka Spruce with very promising results. However, they used 12% MC dry wood for their study, which was dried using small scale laboratory equipment and specific methods that are challenging when applied to a bigger scale. Therefore, development of an economically viable drying method for UK grown softwoods is essential to add significant value to UK grown softwoods.

The overall project aim is designed, not only to provide the development of a new product to the UK market but also, and most importantly, is to provide the deep scientific knowledge to the company in order to better understand wood as a material and improve the quality and productivity by the optimisation of the production procedures.

EXPERIMENTAL

In order to evaluate the appropriateness of the local grown timber as a candidate for CLT production, the mechanical properties and the shear strength of the lap joints was investigated. The first stage of the project was to select three species from the log yard of the company. The species selected were locally grown Sitka Spruce and Larch, and imported Scandinavian Pine which was used as control, as these are the main available timber species.

From each of the species 6 samples were collected randomly from different segment of the same log to represent any variability across the timber. All samples were conditioned in a conditioning room until weight stabilisation. The sample dimensions were 25x25x350 mm. The support span was 280 mm and the speed strain was adjusted to 12 mm min-1 in order for the specimen failure to occur within 60±30 seconds from the start of the load application. The load was applied tangential to the timber's growth rings. The modulus of rapture (MOR) and modulus of elasticity (MOE) was calculated according to equations Eqn. 1 and Eqn. 2 respectively.

$$MOR = (3 \text{ x } Fmax \text{ x } l)/(2 \text{ x } b \text{ x } t^2) \quad (1)$$

$$MOE = (l^3 \text{ x } (F2 - F1))/(4 \text{ x } b \text{ x } t^3 \text{ x } (a2 - a1)) \quad (2)$$

l: support span
b: specimen width at the bending point
t: specimen thickness at the bending point
Fmax: maximum load
F1: 10% of maximum load
F2: 40% of maximum load
a1: strain extension at 10% of maximum load
a2: strain extension at 40% of maximum load

For the adhesion shear strength, from each of the timber species two planed layers were collected randomly from different sections of the same log to represent any variability across the timber. All samples were conditioned in a conditioning room until weight stabilisation. The sample dimensions were 600x70x5 mm. The layers were glued together with the currently used MUF adhesive for laminate products provided by CJT. The layers had a grain orientation of approximately 45^o degrees and laminated with opposite orientation (Figure 1a). The samples were clamped together for 48 hours to ensure proper adhesive curing. Then the samples were cut into smaller samples with dimensions of 100x20x10 mm and cut halfway to the glue line in both sides to expose a glue line area of 20x10 mm Figure 1b. Then the samples were placed into the condition room until weight stabilisation. The samples were subjected to shear strength with a strain speed of 50mm min^{-1}. The adhesion shear strength was calculated according to Eqn. 3.

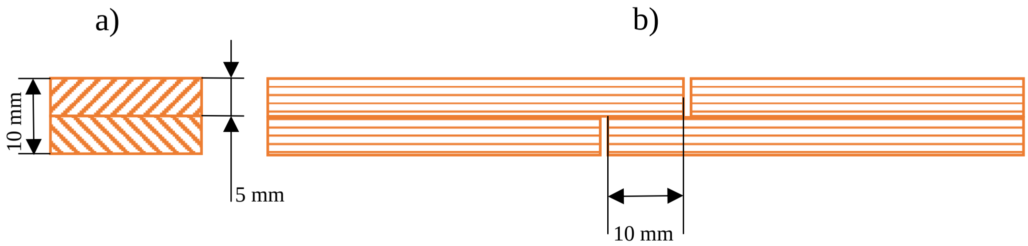


Figure 1: Schematic presentation of adhesion test sample. a) Cross section b) side section

$$\text{Shear strength} = \text{Fmax}/(b \times t) \qquad (3)$$

b: Glue area width
t: Glue area length
Fmax: maximum load

Small scale prototype CLT have been made by conditioned Spruce for demonstration and presented to the company in order to visualise the product perspective (Figure 5). Along with the mechanical testing, Kiln drying trails on local grown Spruce are currently undertaking place and the heat and moisture transfer is recorded. The kiln trials are set up to 70^{o}C and in the presence of steam to achieve relaxation of lignin in order suppress the stresses which lead to twist and bow of the planks. The collected data will be used for the understanding the moisture and heat transfer and will be used for the validation of a multi-physics model simulation. Currently this stage of the project is ongoing and the results will be presented in a future paper. Other UK grown species like Larch and Scots Pine will also undergo the same procedure for the development similar multi-physics simulation.

RESULTS AND DISCUSSION

Results

The MOE and MOR values are presented in Table 1 and the in Figure 2a and b. According to Figure 1a the highest MOE as expected was observed in pine samples. The timber with the second highest MOE was the spruce and the lowest was the Larch. The Larch was the specie with clearly the lower MOE were Spruce and Pine samples had around the same values and because of the SD there was not any clear difference observed.
Similar results were obtained in MOR values (Figure 2b). However, even the MOR SD of the Pine and the Spruce samples are overlapping it appears that Spruce samples has lower values as the highest points of the Spruce SD is significantly lower than the Pine. The Larch MOR values showed the highest SD which is again significantly overlapping Spruce values.

Table 1: MOE and MOR average values. Values in brackets represent the standard deviation (SD)

	Pine	**Spruce**	**Larch**
MOE (MPa)	6946.61 (506.82)	7146.91 (995.93)	5882.52 (1853.13)
MOR (MPa)	63.59 (5.03)	61.85 (6.63)	65.24 (12.77)

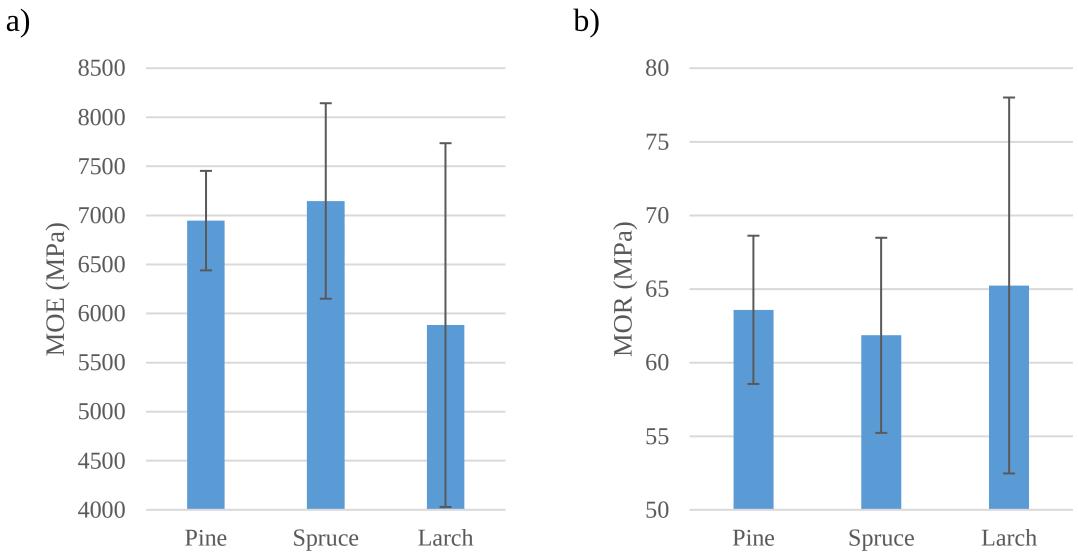


Figure 2: a) MOE and b) MOR in MPa. Error bars representing the standard deviation (SD)

In order to identify the possible similarities between timber species the MOE and MOR raw values were plotted in Figure 3. It seems that there is no significant difference between Pine samples and the Spruce samples, as they are forming a cluster on the up left corner of the graph. The Larch samples on the other hand are clearly forming a different spread cluster that is below the Spruce and the Pine.

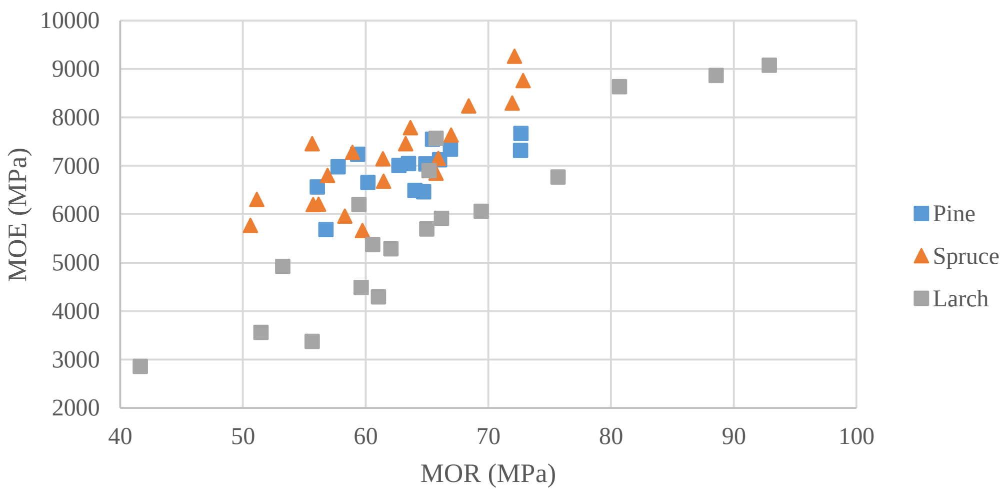


Figure 3: Scatter graph of MOE against MOR

The Lap joint adhesion strength values are presented in Table 2 and the in Figure 4. According to Figure 4 the highest adhesion strength was observed in spruce samples. The timber with the second highest adhesion strength was the pine and the lowest was the Larch. The Larch was clearly the specie with the lowest values whereas Spruce and Pine samples had around the same values and because of the SD, there was not any clear difference observed between these two species. However it was observed that the pine samples had gaps in glue line as a result of poor preparation, resulting to high deviation. Additionally the pine samples with the highest observed values did not show any significant material failure. Whereas the Spruce and especially the Larch samples showed that the failure mainly occurred on the material surface rather than the glue line.

Table 2: Adhesion shear strength

	Pine	Spruce	Larch
Shear strength (MPa)	4.25	5.80	3.04
SD	2.23	2.13	0.99

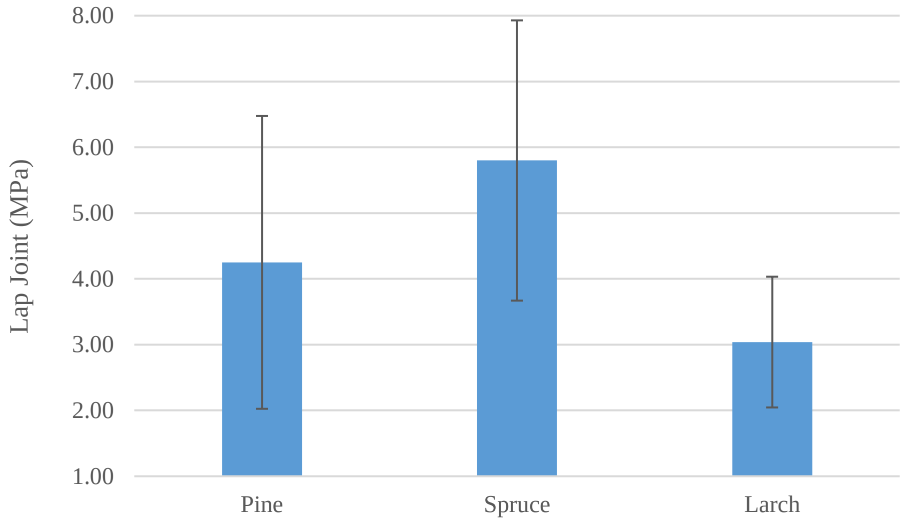
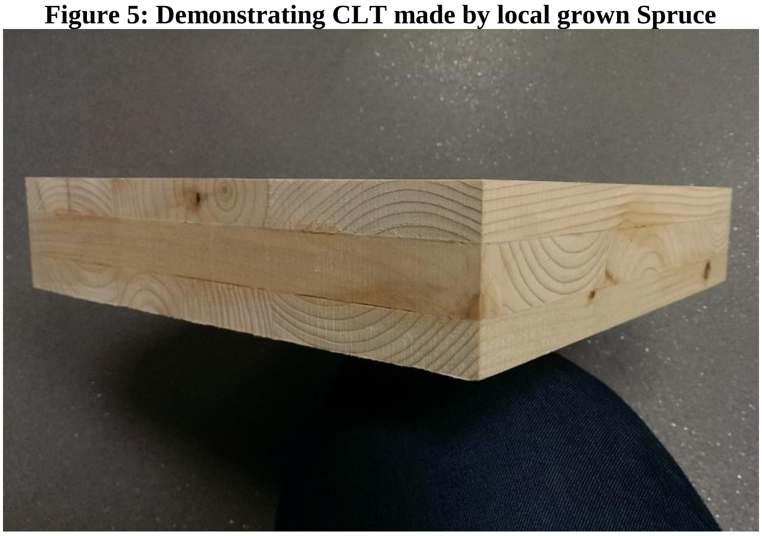


Figure 4: Adhesion strength in MPa. Error bars representing the standard deviation (SD)

Figure 5: Demonstrating CLT made by local grown Spruce



Discussion

By the analysis of the MOE and MOR data it seems that the Sitka Spruce does not significantly differ from the Pine samples whereas Larch had clearly lower values. However, as was expected, Spruce showed higher SD because, UK grown Spruce have significantly wider annual growth rings compared to Scandinavian Pine. The small tight annual growth rings in Scandinavian Pine resulting to a more homogenized material in contrast to wide growth rings of Spruce which is affecting the mechanical behaviour when subjected to load stresses due to larger areas of variation in the material.
The analysis of the adhesion strength data suggests that the Sitka Spruce does not significantly differ from the Pine samples whereas Larch had clearly lower values. However, Spruce appeared to fail on the surface rather on the glue line which means that

the adhesion strength exceeds the material strength properties. Therefore pine could provide stronger bonds but because of the poor sample preparation it was not observed. It is essential to repeat the Lap joint test for the Pine samples in order to estimate more accurately the adhesion strength.

CONCLUSIONS

The mechanical properties investigation showed that Spruce does not significantly differs from the imported Pine and therefore could be used as source material for CLT production. The Larch showed lower values than Spruce, however it could still be considered for CLT production as it is possible to be graded as construction timber. The Kiln trials will be evaluated and the decision for the most appropriate species will be made according to the most economically viable process that takes into account the cost of production, material accessibility and additional investment costs.
The production of an accurate drying simulation model is expected by the end of this project. Furthermore, during this project the company will be benefit not only by the introduction of a new product but also by the knowledge transfer on wood science and the procedures that lead into a successful research and development project.

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